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SOIL CHARACTERISTICS OF A MOLLISOL AND CORN (*ZEA MAYS* L.) GROWTH 20 YEARS AFTER TOPSOIL REMOVAL

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ABSTRACT

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This study presents soil characteristics of a northern corn belt (U.S.A.) mollisol (fine, montmorillonitic, mesic, Typic Argiustoll) 20 years after 0, 30 and 45 cm of topsoil were removed. Evidence of pedogenesis could be observed in the surface horizon of the desurfaced plots, but development has not ameliorated the unfavorable characteristic caused by topsoil removal. Due to reduced organic matter and increased calcium carbonate content, greater fertilizer application rates were required for the desurfaced plots. An adequate level of phosphorus availability will be difficult to establish. The desurfaced plots had a higher mean weight diameter of the soil fraction $\leq$ 9 mm and a higher proportion of massive soil units > 9 mm. Bulk density and clod density of the surface horizon was higher in the desurfaced plots. Desurfaced plots had a higher bulk density with depth. Less available soil water was present in the Ap horizon of the desurfaced treatments. The color of the surface soil appeared to influence soil surface reflectance. The lighter color of the desurfaced plots corresponded to lower soil profile temperatures. Combined characteristics of the desurfaced plots resulted in delayed emergence, reduced plant development and reduced stover and corn (*Zea mays* L.) grain yield.

INTRODUCTION

The removal of topsoil, whether by erosion or by land shaping operations such as levelling or terrace construction, generally results in reduced crop productivity. Several investigators have reported a reduction in the yield of corn (*Zea mays* L.) due to topsoil removal. The reported yield losses range from 75 to 125 kg ha^{-1} year^{-1} per cm of topsoil removed (Smith, 1946; Adams, 1949; Langdale et al., 1979). Topsoil removal reduces productivity through a loss of plant nutrients, reduced water-holding capacity and lower stability of surface-soil structure (USDA-SEA-AR, 1981).

The plant nutrients lost by the removal of topsoil can be replaced, to

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some degree, through increased fertilization of the exposed sub-soil. However, the effect of fertilization on plant growth depends to a large extent on the physical properties of the sub-soil and the climatic conditions at the site (Engelstad et al., 1961; Eck, 1969; Batchelder and Jones, 1972). The water-holding capacity, presence of root impediments and the condition of the soil surface determine the extent to which increased fertilization will restore yields when water is limiting crop growth.

When water relationships were improved through mulching and supplemental irrigation yields were restored to that of the control on a well-fertilized, desurfaced Typic Hapludult (Batchelder and Jones, 1972). Soil-water storage during the growing season was lower on a desurfaced Pullman silty clay loam (Torrertic Paleustoll) compared to undisturbed plots. Sorghum (*Sorghum vulgare* L.) yield reduction on well-fertilized desurfaced plots was attributed to reduced water-holding capacity resulting from topsoil removal (Eck, 1969).

The stability of the soil surface determines the extent to which surface sealing and crusting will occur. Exposure of sub-soils which are low in organic matter can result in lower surface-aggregate stabilities (Shikula, 1961). A degraded soil surface not only reduces soil-water storage by reducing water infiltration, but may also increase the rate of erosion through increased runoff (USDA-SEA-AR, 1981).

Olson (1977) reported the results of an experiment to examine the productivity of a desurfaced Beadle soil (Typic Argiustoll). The topsoil was removed to depths of 0, 30 and 45 cm. The objective was to determine the magnitude of crop production decline due to topsoil removal, and to determine if crop production could be restored through fertilizer management. Results obtained from these trials (concluded in 1973) showed that fertilizer application increased crop yields within a topsoil removal treatment, but did not re-establish crop yield equal to levels obtained with the control (Olson, 1977). Our objective was to examine the chemical and physical properties of the control and desurfaced plots of this soil 20 years after desurfacing, and to determine what effect past desurfacing was exerting on soil productivity.

MATERIALS AND METHODS

The study site is located on a Beadle clay loam (fine, montmorillonitic, mesic, Typic Argiustoll) which is developed in loamy glacial till of late Wisconsin age. It occurs extensively in the southern black glaciated plains (LRA 55C) and loess uplands and till plains (LRA 102B) of the north central part of the U.S.A. It also occurs on 65,000 ha of land in South Dakota, and is typical of many closely related soils of the area (USDA-SCS, 1981).

In 1965, topsoil was removed in increments of 0, 30 and 45 cm from a near level site. Three replications for each topsoil removal treatment were established. After termination of the original study, the desurfaced plot area was maintained in a corn—oats (*Avena sativa* L.) rotation. During the period 1974—1983, fertilizer application was based on standard soil test recommendation from soil samples collected in adjacent control sites. Since desurfacing, the tillage management system has been autumn moldboard plowing with secondary tillage in the spring.

The original plot boundaries were re-established in the autumn of 1983. Individual plot dimensions were 15 × 30 m. Some soil displacement by tillage was observed, so a 3-m border-zone was established along the edge of all plots. Soil test-samples were collected from all plots in the low fertility area of the original experiment. Fertilizer application was based on these analyses.

In the autumn of 1983, the plot area was moldboard plowed. In the spring of 1984, pre-plant herbicide 150 kg ha^{-1} diammonium phosphate (18—46—0) recommended zinc were incorporated by discing, and corn was planted with a commercial 4-row planter on 76-cm-row spacing at a population of 65,000 plants ha^{-1}. Additional recommended herbicide, insecticide and 140 kg ha^{-1} of fertilizer (13—33—13) was banded over the row at planting. Additional nitrogen was sidedressed at first cultivation at a rate of 190 kg ha^{-1} N as ammonium nitrate. Fertilization for a yield goal of 9 t ha^{-1} corn grain were based on South Dakota State University soil test recommendations (Gerwing et al., 1982).

The crop growth parameters which were measured were emergence, plant population, plant height and plant leaf-area at first cultivation, silking date, stover yield and grain yield. Soil temperatures at selected depths within one replication were collected over a 48-h period using thermocouples (3 thermocouples wired in parallel at each depth).

Bulk soil-samples were collected from the 0—15-cm zone after planting in the spring, and after moldboard plowing in the autumn for determination of aggregate size distribution. Aggregate size classes were separated with a rotary-sieve after air drying (Chepil, 1962). Bulk-density samples were collected after harvest by horizon increments using a hydraulic sampling probe (50-mm inside diameter). Clod-density samples were collected at random from each plot after the autumn primary tillage using the method described by Blake (1965).

RESULTS

Profile characteristics

Evidence of pedogenesis can be observed in the surface horizons of the desurfaced plots. Horizon characteristics of the desurfaced and undisturbed plots are summarized in Table I. On the 30- and 45-cm desurfaced plots, the color of the original Bk (now Ap) horizon has changed from an olive brown (2.5 Y 4/4), to a very dark grayish brown (10 YR 3/2) and a

TABLE I

Selected properties of desurfaced plots and undisturbed plots

Top soil removed (cm)	Horizon	Moist color	Depth (cm)	Clay (%, w/w)	Sand (%, w/w)	Organic matter (%, w/w)	$CaCO_3$ (%, w/w)	pH[a]	Available water (%, w/w)	Bulk density (Mg m^{-3})
0	Ap	10 YR 2/1	0–15	45	6	3.7	3.5	6.9	17.8	1.23
	Bw	10 YR 3/2	15–24	33	3	2.8	3.9	7.2	17.6	1.26
	Bk	2.5 YR 4/4	24–72	33	5	2.1	27.7	7.9	13.0	1.38
	C1	—	72–90	27	18	1.4	23.4	8.0	12.8	1.42
	C2	—	90–150	19	54	1.5	17.3	7.8	10.7	1.54
30	Ap	10 YR 3/2	0–20	29	5	3.2	10.0	7.5	16.3	1.37
	Bk	10 YR 5/3	20–46	32	19	1.2	30.6	7.7	14.0	1.43
	C	—	46–150	27	16	0.7	14.2	7.8	15.3	1.57
45	Ap	10 YR 3/3	0–17	34	14	2.2	20.6	7.5	13.4	1.45
	Bk	2.5 Y 4/4	17–47	29	21	1.7	25.3	7.7	10.2	1.48
	C	—	47–150	30	13	1.1	20.2	7.9	17.9	1.58

[a] 1:1 soil—water mixture.

dark brown (10 YR 3/3), respectively. These colors are not as dark as the black (10 YR 2/1) surface (Ap horizon) of the control plot. Both of the desurfaced plot treatments have a surface color that is 1 value-unit lighter than the control area. In addition, a gradation in surface chroma occurs across the plots; a surface chroma of 1 occurs on the control area, while the 2 desurfaced treatments have surface chromas of 2 and 3, respectively. These data indicate that during the 20 years since desurfacing, the surface colors have become darker, but that the deeper the cut the less dark the color. Color differences in the present Ap horizon could result in differential adsorption of radiant energy. The lighter colored desurfaced plots would result in more radiant energy being reflected than would the darker surface horizon of the control plot.

Increases in soil organic matter during the past 20 years are a likely explanation of the change in surface color (Table I). The 30-cm desurfaced plots have experienced a greater increase in organic matter than the 45-cm desurfaced plots, where the increase was only very slight (2.2% vs. 2.1%). Organic matter levels of the present Ap horizons decrease across the treatments as the depth of topsoil removal increases.

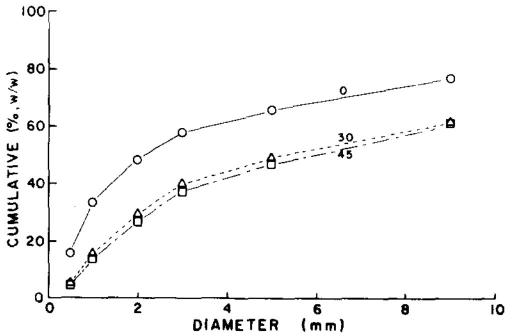

Fig. 1. Cumulative aggregate size distribution of soil fraction ⩽ 9 mm in the Ap horizon of desurfaced (30- and 45-cm) and non-disturbed (0-cm) plots after planting.

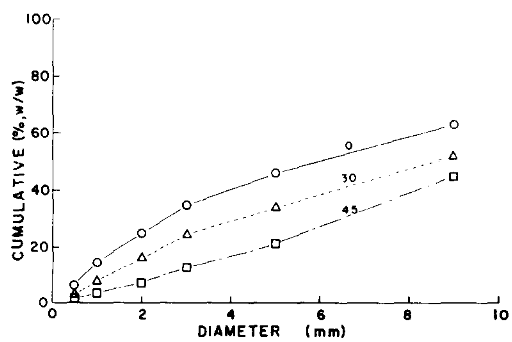

Fig. 2. Cumulative aggregate size distribution of soil fraction ⩽ 9 mm in the Ap horizon of desurfaced (30- and 45-cm) and non-disturbed (0-cm) plots after autumn primary tillage.

Soil pH values of the Ap horizon are higher in the desurfaced plots than in the control areas, which is explained by the much higher $CaCO_3$ contents of the desurfaced plots. Calcium carbonate levels of the Ap horizon of the 2 desurfaced treatments are lower than that of the Bk horizon of the control (Table I). This indicates that $CaCO_3$ has been translocated within both of the desurfaced pedons during the 20 years since desurfacing.

Physical characteristics

Aggregate size distributions of the Ap horizon as presented in Figs. 1 and 2 show a coarser aggregate distribution for the desurfaced treatments for both the spring and autumn sampling period. Other soil physical parameters of the Ap horizon are shown in Table II. Primary autumn tillage, overwinter freezing and thawing and secondary seedbed preparation are reflected in the spring sampling data (Fig. 1). Overseason consolidation and disruption by moldboard plowing caused an overall decrease in the proportion of fine aggregates (Fig. 2). The desurfaced plots had a higher mean weight—diameter (MWD) in the soil fraction $\leqslant$ 9 mm and a greater proportion of massive soil units > 9 mm in size (Table II). This indicates a possible undesirable seedbed which could result in seed—soil contact problems. Mean weight—diameter of the soil fraction $\leqslant$ 9 mm and the proportion of massive soil units > 9 mm increased with increasing depth of topsoil removal (Table II). Bulk density measurements within the Ap horizon show a higher density for the desurfaced plots and indicate no change from the original Bk horizon (Table I). This increase in density is also reflected in the clod density (Table II), and suggests that movement of air and water into and through the soil profile may be restricted as a result of desurfacing.

Soil temperature measurements taken for a 2-day period early in the growing season (Table III) show a decrease in soil profile temperature with desurfacing. The lighter colored desurfaced plots would result in greater reflectance. Interactions between surface density and moisture content could also have an influence on heat transfer within the soil profile.

The available water-holding capacity data, based on the water desorption curves for disturbed soil samples (Table I) show that the Ap horizon of the desurfaced plots will retain less available water between 0.03 and 1.5 MPa than the same horizon in the control plot. This reduction in the amount of water available for plant growth in the top 20 cm, in conjunction with the possible restriction to root growth associated with the desurfaced profiles, could contribute to reduced plant growth and grain yield on the desurfaced treatments.

Fertilizer recommendations

Fertilizer recommendations for a corn grain yield goal of 9 t ha^{-1} based on soil test analyses are shown in Table IV. The average annual corn yield

TABLE II

Mean weight—diameter (MWD) of aggregate fraction $\leqslant$ 9 mm, soil mass > 9 mm, bulk density and clod density of the Ap horizon

Sampling time	Topsoil removed (cm)	MWD of soil fraction $\leqslant$ 9 mm (mm)	Soil fraction > 9 mm (%, w/w)	Bulk density ($Mg\ m^{-3}$)	Clod density ($Mg\ m^{-3}$)
After planting	0	2.3	23	—	—
	30	3.0	38	—	—
	45	3.2	39	—	—
	LSD (0.05)	0.6	6	—	—
After autumn tillage	0	3.2	37	1.23	1.68
	30	3.9	48	1.37	1.75
	45	4.9	55	1.45	1.87
	LSD (0.05)	0.7	7	0.07	0.07

TABLE III

Mean soil temperature measurement for a 2-day period early in the growing season

Date	Topsoil removed (cm)	Mean temperature (°C) at depth (cm)			
		10	20	50	100
30 June 1984	0	23.3	22.4	20.4	17.7
	30	23.2	21.0	19.0	16.9
	45	21.7	20.4	18.0	16.1
1 July 1985	0	23.1	21.6	20.4	17.8
	30	23.7	21.2	19.2	17.1
	45	21.7	20.7	18.2	16.4

of this soil is approximately 6 t ha^{-1}. The lower organic matter content of the Ap horizon in the desurfaced treatments probably resulted in less mineralization of nitrogen. Therefore, for both sampling periods, the recommended nitrogen application rate was clearly higher on the desurfaced soils. The combination of lower organic matter and the presence of $CaCO_3$ would account for decreased phosphorus and zinc availability for the desurfaced plots. In both cases where zinc was recommended, the measured zinc availability was near the upper limit of the marginal response zone (Gerwing et al., 1982).

Crop growth

The crop growth parameters measured are shown in Table V. In the desurfaced treatments, a 3-day delay in emergence was observed. An adequate and uniform plant population was obtained for all treatments. Early in the season, plant height and leaf area show a delay in plant development for the desurfaced plots. This delay was also apparent during the reproductive stage where a 4- and 6-day delay in the date of 50% silking occurred for the 30- and 45-cm desurfacing treatments, respectively. Corn stover production and corn grain yield show significant reductions of approximately 20 and 25% due to desurfacing to 30 and 45 cm, respectively.

Plant nutrient analyses of the ear leaf (leaf opposite and below the ear) at silking are shown in Table VI. Nitrogen, phosphorus and potassium contents were below the sufficiency range for all treatments, but this was probably environmentally induced rather than a treatment effect. In the 30- and 45-cm desurfaced treatments, phosphorus content was at a lower level than in the control treatment, indicating that phosphorus uptake may have had an influence on yield. Zinc content was in the low range for the 0- and 30-cm desurfaced treatments, but was not greatly different from the 45-cm desurfaced treatment and probably did not influence yield.

TABLE IV

Fertilizer recommendations based on soil test analysis for a proposed 9 t ha^{-1} corn yield for the 1984 and 1985 crop-season and fertilizer applied for the 1984 crop

Topsoil removed (cm)	Fertilizer[a] nutrient	Recommendation spring 1984 (kg ha^{-1})	Fertilizer applied spring 1984 (kg ha^{-1})	Recommendation autumn 1984 (kg ha^{-1})
0	N	145	235	65
	P	10	50	0
	K	0	15	0
	Zn	0	0	0
30	N	195	235	80
	P	25	50	30
	K	0	15	0
	Zn	0	0	6
45	N	210	235	125
	P	25	50	30
	K	0	15	0
	Zn	6	6	0

[a]Reported as elemental form.

TABLE V

Corn growth measurement collected during the 1984 crop-season

Measurement	Units	Topsoil removed (cm)				Date of measurement
		0	30	45	LSD (0.05)	
50% emergence	date	27.05	30.05	30.05	—	—
Plant population $\times 10^3$	plants per ha	61.5	57.8	57.3	—	—
Plant height	cm	57	48	43	8	26.06
Leaf-area	cm^2 per plant	779	461	342	233	26.06
50% silking	date	29.07	2.08	4.08	—	—
Stover yield	t ha^{-1}	8.0	6.4	6.0	1.4	7.09
Grain yield	t ha^{-1}	8.7	7.1	6.5	1.6	24.10
Grain moisture	%, w/w	20.6	23.9	21.9	NS	24.10

TABLE VI

Nutrient content of the ear-leaf at silking

Plant nutrient	Units	Topsoil removed (cm)			Sufficiency[a] range
		0	30	45	
N	%, w/w	2.59	2.44	2.53	2.75—3.50
P	%, w/w	0.24	0.19	0.19	0.25—0.40
K	%, w/w	1.53	1.33	1.42	1.71—2.25
S	%, w/w	0.19	0.18	0.18	0.15—0.40
Ca	%, w/w	0.58	0.54	0.53	0.21—0.50
Mg	%, w/w	0.38	0.38	0.36	0.21—0.40
Mn	$\mu g\ g^{-1}$	76	72	69	20—150
Fe	$\mu g\ g^{-1}$	160	141	137	21—50
Ca	$\mu g\ g^{-1}$	15	15	16	6—20
Zn	$\mu g\ g^{-1}$	18	18	20	20—70

[a]Tabular values used by the South Dakota State University Soil Testing Laboratory.

CONCLUSIONS

(1) The loss of topsoil by either mechanical removal, or accelerated erosion has a long-term negative influence on soils. Even after 20 years of fertilization and cropping, the effect of topsoil removal was still evident.

(2) Soil physical properties of the Ap horizon of the desurfaced plots were characterized by larger aggregate size, a greater proportion of massive soil units > 9 mm, higher bulk density, and higher clod density. These physical properties represent a less desirable seedbed than the control. The lighter color of the desurfaced treatments corresponds to lower soil tempera-

tures. Delayed emergence and reduced plant development were observed on the desurfaced plots, even though near optimum moisture conditions ensured an adequate plant population for all treatments.

(3) A higher bulk density of the surface and sub-surface horizons was observed on the desurfaced treatments. This higher density could have an effect on root development through both an increase in mechanical impediment and a reduction in oxygen availability within the rhizosphere.

(4) The desurfaced plots are characterized by a combination of a low organic matter content and a high $CaCO_3$ content in the Ap horizon. Soil tests indicated that phosphorus availability had been reduced in the desurfaced plot areas. Banding of phosphorus near the seed would be the most effective method of application; however, our results indicate that phosphorus was limited even with this type of application. Additional research will be required to determine what procedures will be necessary to correct this apparent phosphorus uptake problem. A higher nitrogen application rate is required because of reduced nitrogen mineralization due to the lower organic matter content in the desurfaced treatments. Borderline zinc deficiency was observed from soil test analyses on the desurfaced treatments; this suggests that zinc availability will need to be monitored.

(5) Pedogenesis has occurred in the surface horizon of the desurfaced treatments. The development of a darker surface color and a granular structure during the past 20 years should have improved the surface soils for crop production. However, these properties have not ameliorated the unfavorable characteristics caused by topsoil removal. Corn yields were 20 and 25% less on the 30- and 45-cm desurfaced treatments as compared to the control plots.

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REFERENCES

Adams, W.E., 1949. Loss of topsoil reduced crop yield. J. Soil Water Conserv., 4: 130.

Batchelder, A.R. and Jones, J.N., Jr., 1972. Soil management factors and growth of *Zea mays* L. on topsoil and exposed subsoil. Agron. J., 64: 648—652.

Blake, G.R., 1965. Bulk density. In: C.A. Black (Editor), Methods of soil analysis — physical and mineralogical properties. Including statistics of measurements and sampling. Agronomy No. 9, Part 1. American Society of Agronomy, Madison, WI, pp. 374—390.

Chepil, W.S., 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc., 26: 4—6.

Eck, H.V., 1969. Restoring productivity on a Pullman silty clay loam subsoil under limited moisture. Soil Sci. Soc. Am. Proc., 35: 578—581.
Engelstad, O.P., Shrader, W.D. and Dumenil, L.C., 1961. The effect of soil surface thickness on corn yields. I. As determined by a series of field experiments in farmer-operated fields. Soil Sci. Soc. Am. Proc., 25: 494—497.
Gerwing, J., Fixen, P., Gelderman, R. and Carson, P., 1982. Fertilizing corn. South Dakota Extension Fact Sheet 432, South Dakota State University, Brookings, SD.
Langdale, G.W., Box, J.E., Jr., Leonard, R.A., Barnett, A.P. and Fleming, W.G., 1979. Corn yield reduction on eroded southern Piedmont soils. J. Soil Water Conserv., 34: 226—228.
Olson, T.C., 1977. Restoring the productivity of a glacial till soil after topsoil removal. J. Soil Water Conserv., 32: 130—132.
Shikula, N.K., 1961. Water-physical properties of eroded soils in the Don Basin. Sov. Soil Sci., 2: 207—212.
Smith, D.D., 1946. Effect of contour planting on crop yields and erosion losses in Missouri. J. Am. Soc. Agron., 38: 810—819.
USDA-SEA-AR, 1981. Soil erosion effects on soil productivity: a research perspective. J. Soil Water Conserv., 36: 82—90.
USDA-SCS, 1981. Land Resouce Regions and Major Land Resource Areas of the United States. Agriculture Handbook 296, Washington, DC, 256 pp.